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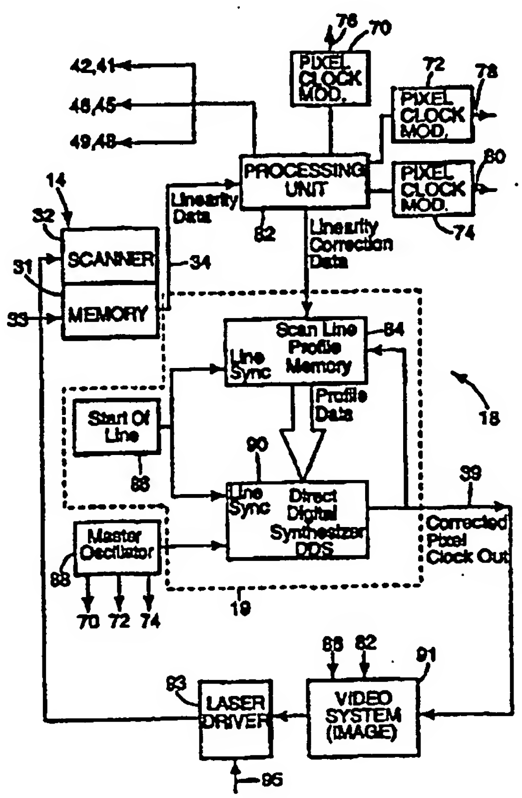
(54) Title: SYSTEM AND METHOD FOR CONTROL OF LASER SCANNERS IN AN IMAGING SYSTEM

(57) Abstract

A scanner module for use in an imaging system includes a laser scanner operable under control of the imaging system for scanning a laser spot along a scan line to write a plurality of pixels along the scan line. The scanner further includes a scanner module memory including pixel placement correction data downloadable to the imaging system for use in controlling the placement of pixels along the scan line. The scanner module memory may further include output power correction data downloadable to the imaging system for use in controlling the output power of the laser scanner in the generation of the plurality of pixels along the scan line. Imaging systems use the correction data stored in the one or more replaceable scanner modules for use in controlling the placement of pixels along the scan line and/or for use in controlling output pwer of the laser scanner. Systems and methods for generating the correction data for the laser scanner modules are also described. Scan correction data can be used to reduce differences in the scan profiles of multiple scanners, such that the multiple scanners produce substantially the same scan profile. In this manner, color planes formed using multiple scanners can be placed in substantial registration with one another, thereby alleviating the visual effects of scan profile differences from scanner-to-scanner.



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SYSTEM AND METHOD FOR CONTROL OF LASER SCANNERS IN AN IMAGING SYSTEM

Field of the Invention

The present invention relates generally to imaging and, more particularly, to control of scanner modules used in imaging systems for producing single color or multiple color images.

Background of the Invention

In conventional electrophotographic printing systems, e.g., image producing systems, a photoreceptor is supported by a mechanical carrier such as a drum, belt, or platen. Typically, the photoreceptor is erased by exposure to an erase lamp which removes any residual charge remaining on the photoreceptor from previous operations. The photoreceptor is then generally uniformly charged, positive or negative, by subjecting the photoreceptor to a suitable charging device, such as, for example, a corona or a charge roll. The charge distribution on the photoreceptor is then altered, i.e., data is written to the photoreceptor, by an image-wise application of radiation, e.g., a laser, to the surface of the photoreceptor creating a latent image corresponding to the image-wise application of radiation on the photoreceptor. Typically, the data is written with a moving, i.e., scanning, laser spot wherein the light sensitive material, i.e., photoreceptor, is translated during the process in a direction generally orthogonal to the scan line. Toner, i.e., ink, is attracted to the photoreceptor in a pattern consistent with the charge distribution of the photoreceptor to render the latent image visible. The toner is then typically transferred, either directly or through an intermediate medium, from the photoreceptor to a receptor material or medium being printed, e.g., paper or film, to yield a print.

Such an imaging system enables the production of high quality images on the receptor material, such as film or paper. Such imaging systems, e.g., electrophotographic printing systems, may include, for example, conventional laser printers, photocopiers, proofers, etc. The sequence of events described above generally produces a single-color image, i.e., a monochrome image. Such

monochrome imaging systems produce a hard copy output in one toner color only, typically black. If the imaging system is to be used to print a different color, the conventional black toner cartridge is removed and replaced with a toner cartridge containing toner of another color, e.g., red. However, such monochrome printing systems still print only a single-color. On the other hand, color printing systems may use three primary colors, typically cyan, magenta, and yellow to produce a color print. In addition, such color printing systems may further also use a fourth color, black. Various techniques have been developed for use of multiple colors in printing systems to produce color prints, such as, for example, those described in U.S. Patent No. 3,832,170, U.S. Patent No. 4,578,331, U.S. Patent No. 4,728,983, and U.S. Patent No. 4,877,698.

To make a color print, the sequence of events described above for a single-color print may be performed three or four times with the appropriate three or four toners, i.e., inks, being applied to a separate latent image for each of the colors, i.e., a multiple pass color printing system. Color prints produced in this manner may be of extremely high quality if each color plane of the color image is well registered with regard to the others. The latent images for a color image in a multiple pass color system are all written with the same laser, e.g., a four-pass color printing system if four colors are used or a three-pass color printing system if three colors are used. As the same laser scanner is writing the data to the photoreceptor for all the latent images, i.e., each color plane, any mechanical, optical, and electronic variations in the printing system which generally affect the writing of such latent images produces effects that are typically undetectable by the unaided eye. In particular, even if the scanner produces a scan profile that includes certain irregularities, such as nonlinear pixel placement, the same scanner is used for each color separation image. Consequently, the same scan profile is reproduced for each color separation image, resulting in substantial pixel placement registration from image to image.

To produce more prints per unit time, printing systems have been developed which employ multiple lasers, e.g., three lasers for a three-color system or four lasers for a four-color system, as opposed to a single laser. For example,

such systems may position multiple lasers and multiple developing stations for the multiple colors interleaved along a line resulting in a single pass color printing system. In other words, the lasers and developing stations are placed in sequence along the photoreceptor path to form respective latent images for different color planes. The registration of latent images with regard to one another in such a single pass color printing system is affected by most of the variations which affect the multiple pass color printing system, including mechanical, optical, and electronic variations in the printing system along with additional constraints. In contrast to single scanner systems, the use of multiple scanners can result in more pronounced registration problems. Specifically, scan profiles can differ between scanners. The different scan profiles associated with the scanners can cause misregistered placement of pixels from color plane to color plane. Misregistration can arise on the photoreceptor in the case of systems that form latent images on top of one another, or upon transfer of the developed images from different areas of the photoreceptor to an output substrate. In either case, the misregistration can produce visible irregularities that affect image quality.

One illustration of such variations and constraints imposed in single pass printing systems is optical irregularity, which can be described in the following general manner. For example, a laser scanner, such as used in laser printers, is a low cost means by which to produce latent images. Optical aberrations exist in such scanners which degrade printing systems. One such optical aberration is scan linearity, i.e., the speed at which the laser scanner scans a laser spot along a scan line of the printing system. If a laser scanner possesses a perfect scan lens, commonly referred to as the f-theta lens, then the focused laser spot will travel along the scan line at a constant velocity and every pixel written by the laser under control of the printing system during the scan will be perfectly placed, i.e., all adjacent pixels will be separated by the same distance. However, generally, there are no cost efficient perfect scan lenses. Therefore, the laser spot traveling along the scan line will typically never travel at a constant velocity. As a result, all pixels along the scan line will not be evenly spaced. Moreover, the degree of nonlinearity may vary between different scanners, particularly due to

manufacturing tolerances applicable to the f-theta lens and other components of the scanner.

Typically, this condition is not noticed by the unaided eye on monochrome prints at typical resolutions such as, for example, 300 dot per inch (dpi), or even 600 dpi, because the errors in pixel placement are generally small. Further, this condition is generally not noticed on prints from multiple pass color printing systems using a single laser scanner because pixel placement errors for a single laser scanner are typically constant and exactly overlay on themselves in the different color planes generated by the printing system to create the color image. In other words, although the scan profile for a single scanner may exhibit nonlinearity, the same nonlinearity applies to each color plane formed by the scanner. Consequently, significant registration problems between the latent images due to scan nonlinearity do not result with use of a single laser scanner.

However, single pass color imaging systems use multiple laser scanners. Each laser scanner has different characteristic nonlinearities associated with the scanner. The latent images from the different laser scanners will be overlaid to produce a color image. Unlike multiple pass systems, registration of the latent images with respect to each other are noticeable by the unaided eye. For example, the small differences in pixel placement error for each laser scanner will manifest themselves as color bands in the print and will thereby degrade the quality of the print produced by the single pass color system at typical resolutions, e.g., 300 dpi, 600 dpi, etc.

Although such pixel placement error manifests itself to the unaided eye more readily in single pass color imaging systems, single laser scanner imaging systems are also affected depending upon the circumstances. As noted above, the unaided eye may not be able to notice the pixel placement error, but if the print generated is utilized for precision applications, e.g., such as precision measurement or machine template systems used in manufacturing processes for producing goods, such pixel placement error may be problematic. In other words, in such precision measurement systems, the measurements taken from the print may be inaccurate due to the pixel placement error and if used, for example, in

computer aided processes, such pixel placement error may lead to manufacturing errors. As such, pixel placement error can be problematic even in monochrome imaging systems and multiple pass color systems which use just a single laser scanner.

Further, in single pass color printing systems using multiple laser scanners, the mechanical, optical, and electronic variations of each laser scanner may produce a laser output having an amplitude that is different from the other multiple laser scanners utilized in the same single pass printing system. As such, the differences in laser scanner power output, which may vary by fractions of a milliwatt, may result in a degraded quality print. The differences in laser scanner power output can result in differential discharge of the photoreceptor for different scanners given common input image data. The differential discharge can affect the development of the resulting latent images, and undermine image quality. Also, the photoreceptor itself may exhibit nonuniform conductivity characteristics across its surface for a given scanner output.

Summary of the Invention

A field replaceable scanner module in accordance with one aspect of the present invention for use in an imaging system includes a laser scanner operable under control of the imaging system for scanning a laser spot along a scan line to write a plurality of pixels along the scan line. The scanner further includes a scanner module memory including pixel placement correction data downloadable to the imaging system for use in controlling the placement of pixels along the scan line.

In one embodiment of the scanner, the scanner module memory further includes output power correction data downloadable to the imaging system for use in controlling the output power of the laser scanner in the generation of the plurality of pixels along the scan line.

An imaging system in accordance with the present invention includes a controller including a scan line profile memory and one or more replaceable scanner modules. Each scanner module corresponds to a color and includes a laser scanner operable under control of the controller for scanning a laser spot

along a scan line to write a plurality of pixels along the scan line. The scanner module further includes a scanner module memory including pixel placement correction data downloadable to the scan line profile memory of the controller for use in controlling the placement of pixels along the scan line.

In another imaging system in accordance with the present invention, the system includes a controller including a memory and two or more replaceable scanner modules. Each scanner module corresponds to a color and includes a laser scanner operable under control of the controller for scanning a laser spot along a scan line to write a plurality of pixels along the scan line. The scanner module further includes a scanner module memory including output power correction data downloadable to the memory of the controller for use in controlling output power of the laser scanner such that the output power of each of the two or more scanner modules is substantially equivalent.

In further embodiments of the systems, the linear correction data and/or the output power correction data is automatically downloaded to the memory of the controller when the imaging system is initialized.

A system for generating correction data for a laser scanner module used in an imaging system is also described. The laser scanner module is operable under control of the imaging system for scanning a laser spot along a scan line to write a plurality of pixels along the scan line. The system includes a light detection apparatus for generating time representative signals of when a laser spot scanned along a scan line associated with the light detection apparatus passes a plurality of points along the scan line. A fixture is used for holding the laser scanner module relative to the light detection apparatus, such that when the laser scanner module is operable, the laser spot is scanned along the scan line associated with the light detection apparatus. The system further includes a processing device for generating pixel placement correction data for use by the imaging system in controlling the placement of pixels along the scan line, wherein the pixel placement correction data is generated based on the time representative signals.

In one embodiment of the system, the light detection apparatus includes an array of n discrete light detectors positioned along the scan line. The light

detectors generate the time representative signals as the laser spot passes each of the discrete light detectors.

In another embodiment of the system, the light detection apparatus includes a single light collecting element positioned along the scan line generating signals as the light impinges thereon and a constant frequency grating including a plurality of separated transmissive regions. The grating is positioned between the single light collecting element and the laser scanner.

In another embodiment of invention, the processing device generates output power correction data based on the amplitude of the time representative signals. The output power correction data is stored in the scanner module memory for use by the imaging system in varying the output power of the laser scanner.

A method of pixel placement correction is also described, the method includes providing a laser scanner having a scan lens that causes the laser scanner to scan a laser spot along a scan line at a nonconstant velocity resulting in pixel placement error along the scan line. Pixel placement correction data associated with the laser scanner is stored in memory of a scanner module containing the laser scanner prior to the laser scanner being utilized with an imaging system. The scanner module is positioned in an imaging system for operation and control thereby. The pixel placement correction data is downloaded to memory of the imaging system for use by the imaging system in controlling placement of pixels to correct for the pixel placement error.

In another aspect, the present invention is directed to a system and method for laser scan control, particularly in a multi-color electrophotographic imaging system that incorporates multiple laser scanners. The system and method make use of scan correction data to adjust the scan profile of each laser scanner. The scan profile may characterize the laser scanner in terms of pixel placement and/or laser output power. The scan correction data represents adjustments necessary to calibrate each laser scanner to a target scan profile. For example, the scan correction data may include pixel placement correction data representing adjustments necessary to achieve a target pixel placement profile. The scan correction data may include scan line correction data that enables adjustment of

pixel placement along a scan line. The scan correction data compensates for scan profile differences between different scanners. The scan correction data also may include output power correction data representing adjustments necessary to achieve a target output power profile, e.g., to compensate for nonuniform conductivity across the photoconductor.

Pixel placement differences between different scanners can result in misregistration of latent images formed by the scanners. The differences can stem from different degrees of nonlinearity in the scanners. The pixel placement correction data, in accordance with an embodiment of the present invention, can be applied to adjust the pixel clock frequency applied to each scanner, thereby generating a substantially common pixel placement profile from scanner-to-scanner. The substantially common, or "target," profile can be linear or nonlinear so long as it is the same for each scanner. With a substantially constant pixel placement profile, the latent images generated by the multiple scanners can be formed in substantial registration with one another, either on a photoreceptor surface in the event the latent images are formed and developed on top of one another, or on an output surface in the event the latent images are formed at different positions, developed, and then transferred to another surface on top of one another. In either case, application of the pixel placement correction data can alleviate the undesirable visual effects produced by misregistration in color planes produced by development of the latent images.

Output power differences between multiple scanners can result in differential discharge of the photoreceptor for common laser drive data. Moreover, the photoreceptor can exhibit nonuniform conductivity across the photoreceptor surface, giving way to image quality degradation. With power output correction data that characterizes the output of each scanner, multiple scanners in an electrophotographic imaging system can be calibrated to desired laser output intensities given common laser drive data. In this manner, differences in laser response to drive data or photoreceptor nonuniformity can be reduced. Consequently, the visual effects of varying output power or photoreceptor nonuniformity can be alleviated, contributing to enhanced image quality.

The present invention provides, in one embodiment, a laser scanning system comprising a first laser scanner that scans a first laser beam with a first scan profile, a second laser scanner that scans a second laser beam with a second scan profile, and a scan controller that controls the first and second laser scanners to reduce differences between the first and second scan profiles.

In another embodiment, the present invention provides a method for controlling a plurality of laser scanners in a laser scanning system, the method comprising driving a first laser scanner to scan a first laser beam, wherein the first laser scanner has a first scan profile, driving a second laser scanner to scan a second laser beam, wherein the second laser scanner has a second scan profile; and controlling the first and second laser scanners to reduce differences between the first and second scan profiles.

In a further embodiment, the present invention provides a laser scanning system for forming a plurality of color separation latent images in an electrophotographic imager, the system comprising a first laser scanner that scans a first laser beam to form a plurality of first pixels along a first scan line on a photoreceptor surface, the first pixels forming a first latent image, wherein the first pixels are placed along a scan line in the first latent image according to a first pixel placement profile, a second laser scanner that scans a second laser beam to form a plurality of second pixels along a second scan line on the photoreceptor surface, the second pixels forming a second latent image, wherein the second pixels are placed along a scan line in the second latent image according to a second pixel placement profile, and a controller that controls the first laser scanner based on a first pixel clock frequency, the controller adjusting the first pixel clock frequency based on pixel placement correction data to reduce differences in the first and second pixel placement profiles such that the first and second latent images are formed on the photoreceptor surface in substantial registration with one another.

Also, the present invention provides, in one embodiment, a laser scanning system for forming a plurality of color separation latent images in an electrophotographic imager, the system comprising a first laser scanner that scans

a first laser beam to form a plurality of first pixels along a first scan line on a photoreceptor surface, the first pixels forming a first latent image representative of a first color separation image, wherein the first pixels are placed along the scan line according to a first pixel placement profile, a second laser scanner that scans a second laser beam to form a plurality of second pixels along a second scan line on the photoreceptor surface, the second pixels forming a second latent image representative of a second color separation image, wherein the second pixels are placed along the second scan line according to a second pixel placement profile, memory that stores first pixel placement correction data representing a correction of thc first pixel placement profile relative to a target pixel placement profile, and second pixel placement correction data representing a correction of the second pixel placement profile relative to the target pixel placement profile, a first direct digital synthesizer that generates a first pixel clock frequency and adjusts the pixel clock frequency based on the first pixel placement correction data, a second direct digital synthesizer that generates a second pixel clock frequency and adjusts the second pixel clock frequency based on the second pixel placement correction data, and a scan controller that controls the first scanner based on the first pixel clock frequency and controls the second scanner based on the seocnd pixel clock frequency to reduce differences in the first and second pixel placement profiles such that the first and second latent images are formed on the photoreceptor surface in substantial registration with one another.

In an added embodiment, the present invention provides a method for controlling two or more laser scanners to form a plurality of color separation latent images in an electrophotographic imager, the method comprising driving a first laser scanner to scan a first laser beam to form a plurality of first pixels along a first scan line on a photoreceptor surface, the first pixels forming a first latent image representative of a first color separation image, wherein the first pixels arc placed along the first scan line according to a first pixel placement profile, driving a second laser scanner to scan a second laser beam to form a plurality of second pixels along a second scan line on the photoreceptor surface, the second pixels forming a second latent image representative of a second color separation image,

wherein the second pixels are placed along the second scan line according to a second pixel placement profile, generating first pixel placement correction data representing a correction of the first pixel placement profile relative to a target pixel placement profile, generating second pixel placement correction data representing a correction of the second pixel placement profile relative to the target pixel placement profile, using a first direct digital synthesizer to generate a first pixel clock frequency, the first direct digital synthesizer adjusting the first pixel clock frequency based on the first pixel placement correction data, using a second direct digital synthesizer to generate a second pixel clock frequency, the second direct digital synthesizer adjusting the second pixel clock frequency based on the second pixel placement correction data, applying the first pixel clock frequency to the first scanner and applying the second pixel clock frequency to the second scanner to reduce differences in the first and second pixel placement profiles such that the first and second latent images are formed on the photoreceptor surface in substantial registration with one another.

Brief Description of the Drawings

Figure 1 is a diagrammatic illustration of a single pass color printing system utilizing scanner modules in accordance with the present invention.

Figure 2 is a diagrammatic illustration of a laser scanner of one of the scanner modules of Figure 1.

Figure 3 is a block diagram illustration of the printer controller of Figure 1 along with a scanner module.

Figure 4 is a block diagram of a correction data generation system in accordance with the present invention.

Figure 5 is a diagrammatic illustration of a portion of one embodiment of the correction data generation system as shown in Figure 4, and further including a laser scanner such as shown in Figure 2.

Figure 6 is a flow diagram of a pixel placement correction data generation method for the embodiment shown in Figure 5 to generate pixel placement correction data in accordance with the present invention.

Figure 7 is a diagrammatic illustration of a portion of an alternative embodiment of the correction data generation system as shown in Figure 4, and further including a laser scanner such as shown in Figure 2.

Figure 8 is a flow diagram of a pixel placement correction data generation method for the embodiment shown in Figure 7 to generate pixel placement correction data in accordance with the present invention.

Figure 9 is a flow diagram of a power output correction data generation method for use with either of the embodiments shown in Figures 5 or 7 to generate power output correction data in accordance with the present invention.

Detailed Description of the Embodiments

An embodiment of the present invention shall be described with reference to Figures 1-9. First, an illustrative printing system 10 using a plurality of scanner modules 14-17 shall be described with reference to Figures 1-3. Each scanner module 14-17 may be a field replaceable scanner, if desired. Thereafter, a correction data generation system 100 and various embodiments thereof, including methods of generating pixel placement correction data and power output correction data, shall be described with reference to Figures 4-9. In one embodiment, the present invention facilitates field replacement of laser scanner used in imaging systems. In this and other embodiments, the present invention can facilitate registration of latent images produced by two or more laser scanners having different scan profiles. The present invention performs this function by electronically generating scan correction data which can be stored in the memory of a scanner module prior to being used in an imaging system. The imaging system downloads the scan correction data to correct the scan profile, e.g., for use in correcting pixel placement error of the laser scanner and/or output power of the laser scanner relative to a target scan profile.

An illustrative printing system 10 using a plurality of scanner modules 14-17 is shown diagrammatically in Figure 1. The scanner modules 14-17 in system 10 can be field replaceable. The printing system 10 is a four-color, single pass electrophotographic printing system operable under control of printer controller

18. The printing system 10 includes a photoreceptor 12 which may be mechanically supported in a printer housing such as by belts allowing for rotation of photoreceptor 12. Photoreceptor 12 is first conventionally erased with an erase lamp (not shown). Any residual charge left on the photoreceptor 12 after the preceding cycle is preferably removed by the erase lamp and then conventionally charged using a charging device (not shown). Such procedures are well known in the art.

When the photoreceptor is charged, the surface of the photoreceptor 12 is generally uniformly charged, such as to around 600 volts. Thereafter, laser scanner 49 of scanner module 17, similar to the laser scanner as shall be described with reference to Figure 2, exposes the surface of photoreceptor 12 to radiation, i.e., laser beam 24, in an image-wise pattern corresponding to a first color plane of the image to be reproduced.

With the surface of the photoreceptor 12 so image-wise charged, charged pigment particles, e.g., in liquid ink, of developer station 28 corresponding to the first color plane will migrate to and plate upon the surface of photoreceptor 12 in areas where the surface voltage of the photoreceptor 12 is less than the bias of electrode 228 associated with developer station 28. The charge neutrality of the pigment particles of the developer station 28 is maintained by negatively charged counter ions which balance the positively charged pigment particles. Counter ions are deposited on the surface of photoreceptor 12 in areas where the surface voltage is greater than the bias voltage of electrode 228 associated with developer station 28.

At this stage, photoreceptor 12 contains on its surface an image-wise distribution of plated pigment particles, such as "solids" drawn from liquid ink, from developer station 28 in accordance with a first color plane. Although dry toner systems can benefit from application of the present invention, liquid inks will be described herein for purposes of illustration. The surface charge distribution of photoreceptor 12 has also been recharged with plated ink particles as well as with transparent counter ions from liquid ink from the developer station 28, both being governed by the image-wise discharge of photoreceptor 12 due to

the laser scanner 49. Thus, at this stage, the surface charge of photoreceptor 12 is also quite uniform. Although not all of the original surface charge of photoreceptor 12 may have been obtained, a substantial portion of the previous surface charge of photoreceptor 12 has been recaptured. With such solution recharging and/or active recharging by an intermediate charging station, photoreceptor 12 is now ready to be processed for the next color plane of the image to be reproduced.

As the photoreceptor 12 is rotated, photoreceptor 12 next is image-wise exposed to radiation from laser scanner 46 corresponding to a second color plane. The second color plane of the image is then developed by developer station 27. The developer station 27 contains another liquid ink of the second color and is associated with electrode 227 for creating a pattern of solid color pigments on the surface of the photoreceptor 12 corresponding to the second color plane. Likewise, as photoreceptor 12 continues to rotate, a third color plane of the image is produced using laser scanner 42 and developer station 26 including a third color ink and electrode 226. Further, as the photoreceptor 12 rotates yet further, a fourth color plane is deposited upon photoreceptor 12 using laser scanner 32 and developer station 25 including a fourth color ink and electrode 225. The completed four-color image is then transferred, either directly or indirectly, to a medium through various techniques that may include transfer rollers, heat, and/or pressure, etc. The resultant "print" is a hard copy manifestation of the full four-color image.

One skilled in the art will recognize that Figure 1 is only one illustrative printing system which may benefit in accordance with the present invention and that this illustrative diagram is in no way to be taken as limiting to the types of imaging systems for which the present invention is advantageous, nor as the only configuration for such multiple laser single pass systems. For example, although the apparatus as described above is a four-color, single pass system, the present invention may also be adapted for use in any multiple color image printing system having two or more color planes, or "separations." Further, advantages of various aspects of the present invention are not limited to color or single pass systems, but

are also beneficial for monochromatic image printing systems or multiple pass color image printing systems. Likewise, the configurations for all of such systems may vary greatly. For example, the systems may use dry ink for developing the latent images as opposed to liquid ink, or any other type of developing process known to one skilled in the art. Further, the system may include any receptor material wherein a latent image can be formed by the laser scanner and transferred to another medium, e.g., photopolymers, resists, etc.

Further, although the present invention is described with respect to electrophotographic imaging systems, the present invention is applicable to any repetitive non-linear scanner or imaging system (e.g., photocopiers, copiers, printers, proofers, etc.) including such a repetitive non-linear scanner. For example, the present invention is applicable to galvanometer scanners, i.e., self resonating scanners. Further, for example, it will be recognized that the present invention facilitates the field replacement of laser scanners useful in many other types of imaging systems, such as in laser scanners useful in imaging photographic elements, in laser scanners useful in imaging photothermographic elements of the type described in U.S. Patent Nos. 5,434,043 and 5,545,515; in laser scanners useful in imaging printing plate elements of the type described in European Laid Open Patent Application No. 652,483 A1; as well as in the laser scanners useful in imaging electrophotographic elements of the type described herein and elsewhere. The present invention is beneficial for use with any imaging system where a repetitive non-linear scanner is used, and as such, the present invention is not limited to the imaging systems illustratively described herein.

In general, with reference to Figure 1, laser scanner 49 imparts image information associated with a first color plane, or "separation," of the image, laser scanner 46 imparts image information associated with a second color plane of the image, laser scanner 42 imparts image information associated with a third color plane of the image, and laser scanner 32 imparts image information associated with a fourth color plane of the image. Although each of the laser scanners 49, 46, 42, and 32 are associated with a separate color of the image and operate in a

manner as described above, for convenience the following description of the laser scanner with reference to Figure 2 shall be limited to scanner 32 of scanner module 14, but such description is equally applicable to the other scanners.

Laser scanner 32 includes a suitable source 60 of high intensity electromagnetic radiation, such as a solid state laser source. However, any suitable lasing source of high intensity electromagnetic radiation may be utilized. The radiation may be a single beam or an array of beams, represented generally as light beam 21. Further, individual beams in such an array may be individually modulated. The laser source 60 for the laser scanner 32 as generally shown in Figure 2 is typically an infrared diode laser with emission wavelengths closely matched to the absorption band of the photoreceptor. In many cases, the laser will have an emission wavelength of over about 700 nanometers. Specially selected wavelengths in the visible region may also be useable with some combinations of colors.

The radiation or light beam 21 impinges at laser spot 61 on photoreceptor 12 along scan line 13 which lies generally perpendicular to the direction of movement, i.e., rotation, of photoreceptor 12 (Figure 1) and at a fixed position relative to the charging device (not shown) which charges the surface of the photoreceptor 12 after erasure. It is the scanning of the laser spot 61 by the laser scanner 32 along the scan line 13 for which correction is required such that pixel placement effectively registers images which are written by the multiple laser scanners 49, 46, 42, and 32 onto photoreceptor 12.

The laser spot 61 scans and exposes photoreceptor 12 preferably while maintaining exact synchronization with the movement of photoreceptor 12. The image-wise exposure causes the surface charge of photoreceptor 12 to be reduced significantly wherever the laser spot impinges as previously described. Areas of the surface of photoreceptor 12 where the radiation does not impinge, or where such impingement corresponds to an area of low intensity radiation, are not appreciably discharged. Therefore, when photoreceptor 12 exits from under the radiation, its surface charge distribution is proportional to the desired image information. The radiation (a single beam or an array of beams) from laser scanner

32 is modulated in response to image signals for any single color plane from a suitable source such as printer controller 18 (Figure 1).

In the laser scanner 32 of Figure 2, the light beam 21 is provided from collecting optics 65 and strikes a suitable scanning element such as, for example, a rotating polygonal mirror 68. The light beam 21 then passes through a suitable scan lens 64, e.g., an f-theta lens, to focus the radiation at a specific position along scan line 13 with respect to photoreceptor 12. It should be appreciated by those skilled in the art that other scanning mechanisms, such as an oscillating mirror, modulated fiber optic array, waveguide array, or suitable image delivery system, may be used in place of or in addition to a polygonal mirror. For digital half-tone imaging, it is preferred that radiation should be able to be focused to diameters of less than about 42 microns at the one-half maximum intensity level assuming a resolution of 600 dpi because the center-to-center distance between pixels for 600 dpi printing systems is about 43 microns. However, lower or higher resolutions may also be acceptable. Further, in some applications, it is preferred that scan lens 64 be able to maintain the beam diameter across at least a 12 inch (30.5 centimeters) width, e.g., for so-called A3 format printing. In other applications, smaller or larger widths may be appropriate.

The polygonal mirror 68 typically is rotated conventionally at a constant speed by controlling electronics which may include a brushless DC motor and controller. With the focused laser spot 61 scanned in scan direction 62 across the photoreceptor 12 along the scan line 13, photoreceptor 12 is moved orthogonal to the scan direction at constant velocity past the scan line 13 where the laser spot impinges upon photoreceptor 12. The ratio between the scan rate produced by the polygonal mirror and photoreceptor 12 movement speed is maintained substantially constant and selected to obtain the required resolution and image size of laser modulated information and overlap of scan lines for the correct aspect ratio of the final image. For example, for high quality imaging, it is preferred that the polygonal mirror rotation and photoreceptor 12 speed are set so that at least 600 scans per inch, and still preferably 1200 scans per inch, are imaged on

photoreceptor 12. Photoreceptor 12 can travel, for example, at about 3 inches per second (7.6 centimeters per second).

Scanner 32 includes all the necessary elements required to scan a well-focused laser beam 21 over a specified scan length (L) on a surface of the photoreceptor 12. However, the scan lens 64, e.g., an f-theta lens, resident for focusing the beam 21 is not a perfect scan lens able to focus laser spot 61 along the scan line 13 of the photoreceptor 12 at a constant velocity. Therefore, pixels placed along the scan line 13 are not evenly spaced if such pixel placement error is not corrected. If uncorrected, registration problems may occur as described in the Background of the Invention section. In particular, different degrees of nonlinearity between different scanners can produce varying scan profiles. The varying scan profiles can result in differential pixel placement between the scanners such that the resulting images are misregistered relative to one another.

To correct for such pixel placement error, or at least ensure substantially the same pixel placement error from scanner-to-scanner, the present invention utilizes a modified video pixel clock rate, or "frequency." The pixel clock rate can be modified during the scanning of the laser spot along the scan line such that pixels are generally evenly spaced along the scan line. Alternatively, the pixel clock rate can be modified for each scanner such that the pixels are placed at substantially common positions by each scanner, notwithstanding potential nonlinearity. In other words, even if scan nonlinearity continues to exist, the pixel clock rate is adjusted to achieve a substantially common degree of nonlinearity among the scanners. In this manner, the images formed by the scanners can be formed with a substantially common scan profile, resulting in substantial registration with one another. Such correction is further described below. In order to modify each pixel clock for each scanner appropriately so as to provide for correct pixel placement by each scanner 49, 46, 42, 32, pixel placement correction data must be generated and provided to the printer controller 18 for use in modifying the video pixel clock rate during each line scan.

In accordance with the present invention, as shown in Figure 1, each scanner 49, 46, 42, and 32 is only a portion of the respective scanner modules 14-

17, which can be field replaceable. Each of these scanner modules 14-17 also contains a memory 48, 45, 41, and 31, respectively. Further, each of such scanner modules includes ports for writing to the memory and reading from the memory (such as represented by 33 and 34 for scanner module 14) so that external sources can communicate with the memory 31, 41, 45, and 48 of each scanner module 14-17.

Each of the memories 31, 41, 45, and 48 is non-volatile, i.e., the data stored therein is not lost when power is turned off. Further, each memory is large enough to hold one or more arrays of scan correction data, such as pixel placement correction data and/or power output correction data, which are written to the memory by an off-line correction data generation system, e.g., such as a test fixture in the scanner manufacturer's shop, as further described below with reference to Figures 4-9. The memory may include, for example, a pixel placement error look-up table which would be organized so as to enable pixel placement correction to be performed for any constant angular velocity of a rotating scanning element within a specified range of the scanner and for any video signal frequency selected for a desired scanner application. Also, the memory may include a power output error look-up table that sets forth scan correction values specifying corrections for respective laser drive input values. With the pixel placement correction data and/or power output correction data stored in memory of the scanner modules 14-17 and each scanner module 14-17 being a self-contained scanner, i.e., the correction data in the memory being particularly applicable to the scanner of a particular scanner module, easy field replacement of the scanner modules is facilitated with the applicable correction data always being available for use by the printer controller 18 of printing system 10.

With reference to Figure 3, printer controller 18 which uses the correction data stored in the respective memories of scanner modules 14-17 shall be described. It should be readily apparent that although the description is primarily with reference to scanner module 14, such operation is applicable to each of the other scanner modules 15-17 as well. In other words, each scanner module 14-17

may include its own scan control electronics that communicate with and form part of the overall printer controller 18. The printer controller 18 includes a processing unit 82 for control of the scanner modules 14-17. The processing unit 82 provides for formatting correction data from the scanner memory 31 for satisfying printing requirements of various printing systems (e.g., for different scanner speeds, duty cycles, etc.), as well as for satisfying the requirements of the pixel clock modification circuitry 19 which includes the use of a direct digital synthesizer 90 or any other method of varying the pixel clock such as a phase locked loop. Thus, each scanner module 14-17 may include its own pixel modification circuitry 19, which may further include a direct digital synthesizer 90.

The controller 18 also includes an addressable video (image) system 91. The video system 91 stores the image(s) to be scanned by the laser scanner 32. The system 91 receives the corrected pixel clock output 39, as described further below, along with a line sync signal from start of line detector 86 for addressing the pixels of image(s) stored in the video system 91.. An output representative of the pixels addressed is provided to laser scanner line driver 93 which provides an output, e.g., laser drive current, to the scanner 32 for modulation of the lasing source 60 of the laser scanner 32 of the scanner module 14. It should be readily apparent that any addressable video system which provides an output as a function of an input video pixel clock may be utilized in accordance with the present invention and that the present invention is in no manner limited to any particular video system.

The processing unit 82 includes information that indicates that the scanner modules 14-17 operably connected thereto include correction data for use in controlling the laser scanners of the various scanner modules 14-17. Thus, when a scanner module is placed in position for use in the printing system, printer controller 18 recognizes that before print operations are to be performed, the printer controller 18 must access the memory of the scanner module for obtaining pertinent correction data. Any method of communicating such correction data between the laser scanner modules and the processing unit may be used. For example, the correction data may be immediately downloaded to the processing

unit when the scanner module is inserted into a printing system and power is supplied thereto for initializing the module.

In addition to the processing unit 82, the printer controller 18 further includes video pixel clock modification circuitry 19 to modify a master oscillator signal resulting in the corrected pixel clock output 39 for use by the video system 91 in controlling pixel placement by scanner 32 of scanner module 14. Likewise, printer controller 18 includes pixel clock modification circuitry 70, 72, and 74 for use in providing corrected pixel clock output signals 76, 78, and 80 for use by the video system 91 in controlling the other scanner modules 15-17 via other laser drivers. For convenience, the printer controller 18 shall further be described with reference only to scanner module 14 as operation with respect to the other scanner modules 15-17 is substantially identical.

The memory 31 of scanner module 14 may include pixel placement correction data and/or power output correction data. As previously described, the pixel placement correction data is utilized for modifying the pixel clock frequency such that the pixels across the entire scan line are substantially evenly spaced or, alternatively, spaced according to some linear or nonlinear target scan profile. The power output correction data can be utilized such that the focused beam impinging on the photoreceptor 12 of the printing system 10 has the same energy at the laser spot impinging upon the photoreceptor 12 as each of the other laser spots impinging upon the photoreceptor 12 using the other laser scanners of the scanner modules 15-17. Alternatively, the power output correction data can be utilized to modulate the energy of the beam to compensate for nonuniform conductivity characteristics across the photoreceptor.

The power output correction data can be of a single value stored in memory 31 of scanner module 14 as the desired power output from the laser scanner 32 is desired to be constant during the entire printing process. Alternatively, the power output data may be arranged to compensate for nonuniform conductivity across the photoreceptor, and therefore vary as a function of the position of a particular pixel or scan line on the photoreceptor. Generally, the pixel placement correction data may include any number of values, or

coefficients, such that the pixel clock frequency can be modified every n pixel clock transitions, wherein n is an integer greater than or equal to 1. Preferably, n is in the range of about 16 pixel clock transitions to about 256 pixel clock transitions. In other words, the pixel clock frequency is modified every n pixels in proportion to the laser spot's deviation from ideal spot placement. In this manner, the pixel clock frequency can be varied as the laser spot travels along the scan line.

For the printer controller 18 to utilize the correction data input to memory 31 via port 33, the printing system 10 when initialized or powered-up, or at any other time such as reset, etc. downloads the correction data to the processing unit 82 for use in performing the correction functions desired. As indicated above, the processing unit 82 recognizes that the scanner module 14 includes memory 31 having correction data therein for use in controlling the particular laser scanner 32. Therefore, upon such recognition or at a time prior to needing the correction data, the processing unit 82 downloads the correction data from memory 31. Likewise, it downloads the correction data from the memories of the other scanner modules 15-17 upon recognition that they also include such correction data.

Typically, the laser scanner 32 is modulated at a fixed clock rate under control of the pixel clock. To increase the accuracy of pixel placement using the pixel placement correction data from memory 31, the clock speed is dynamically varied to compensate for the placement error induced by the laser scanning system, which may be nonlinear, relative to a target scan profile, and, in particular, the scan lens 64. The target scan profile may represent an ideal linear scan profile, or some other scan profile that is chosen as the common scan profile for each of the various scanners. The pixel clock frequency must be dynamically changed at a fast enough response time to meet the high scanning rate requirements of the printing system. In order to provide such a modified pixel clock frequency, e.g., corrected pixel clock output 39, the pixel clock modification circuitry 19 is utilized.

Pixel clock modification circuitry 19 includes scan line profile memory 84, start of line detector 86, and direct digital synthesizer (DDS) 90. The processing

unit 82 communicates the pixel placement correction data to scan line profile memory 84 of the pixel clock modification circuitry 19. Likewise, it provides pixel placement correction data associated with the other scanner modules to the pixel clock modification circuitry 70, 72, and 74, respectively. Such scan line profile data, i.e. data corresponding to the pixel placement correction data, is provided to the direct digital synthesizer 90 as required.

The direct digital synthesizer 90 outputs a frequency, i.e., corrected pixel clock output frequency 39, which is proportional to an input master oscillator frequency from master oscillator 88 as modified as a function of the pixel placement correction data from scan line profile memory 84. The direct digital synthesizer 90 has the ability to dynamically change its output frequency with a fast enough response time to meet the high speed requirements of the pixel clock for data rates as utilized in printing systems, such as printing system 10. For example, the direct digital synthesizer 90 may be an AD9955 or AD9850 available from Analog Devices of Norwood, Massachusetts.

The scan line profile memory 84 is used to hold the pixel placement correction data associated with the laser scanner 32. This pixel placement correction data is then fed to the direct digital synthesizer 90 which produces a waveform whose frequency follows a profile designed to compensate for the inaccuracies of the laser scanner 32. The corrected pixel clock output 39 may be provided to a phase locked loop which quickly locks onto the changes in the waveform produced by the direct digital synthesizer 90 such that a more stable corrected pixel clock output 39 is provided. For example, the phase locked loop may include a phase comparator for receiving the output from the direct digital synthesizer 90 and for providing a phase compared signal to a loop filter. The loop filter would provide a filtered signal to a voltage controlled oscillator which outputs a corrected pixel clock output frequency. The output would also be provided to a divide by N circuit for use in providing a feedback closed-loop signal to the phase comparator. Such phase locked loop circuits are commonly known in the art and will not be described in detail herein.

Application of the DDS output to the phase locked loop may be particularly desirable for applications requiring higher pixel clock frequencies. Specifically, a phase locked oscillator can be used to accurately step up, or multiply, the frequency of the DDS output to a desired pixel clock frequency. A higher pixel clock frequency may be desired for higher resolution or higher speed scanning systems. For example, to maintain throughput efficiency, a 600 or 1200 dpi system may require a higher pixel clock frequency than a 300 dpi system, particularly for larger format printing. In other words, increased pixel resolutions in combination with larger formats, e.g., 11 inches by 17 inches, can tax the throughput efficiency of an imaging system for a given range of pixel clock frequency. At the same time, however, a direct digital synthesizer exhibiting increased frequency range capabilities may be unavailable or undesirably expensive. In this case, the lower frequency output of direct digital synthesizer 90 can be modified via the phase locked loop As an example, a direct digital synthesizer 90 having a maximum operating frequency range of 25 MHz could be applied to a phase locked oscillator to achieve a higher pixel clock frequency, e.g., 100 MHz. In this manner, a phase locked loop can be used to maintain throughput efficiency while allowing scan profile correction.

The corrected output pixel clock frequency from the direct digital synthesizer 90 is provided as a feedback to scan line profile memory 84. The corrected pixel clock feedback is used in requesting a new DDS output frequency every n pixels, where n is any integer from one to the length of the line in pixels, e.g., preferably where n is equal to 16 pixels to 256 pixels as previously described.

The scan line profile memory 84 and direct digital synthesizer 90 can be synchronized by start of line detector 86. For example, a start of scan line signal may be provided by recognizing that the laser spot 61 is at the edge of the photoreceptor 12, or is at the beginning of the photoreceptor 12, or any other technique of recognizing that a new scan line is being initiated. Further, as shown in Figure 3, the master oscillator 88 also provides the master oscillator input to the other pixel clock modification circuits 70, 72, and 74 utilized for modifying the

pixel clock to generate the corrected pixel clocks 76, 78, and 80 for use in correction of pixel placement error for the other scanner modules 15-17.

The master oscillator input is generally equal to the pixel clock multiplied by a constant (k), where k represents the accuracy required to synchronize the pixel placement to the asynchronous start of line signal, i.e., line sync. According to Nyquist theory, k should be at least two and, to remove alliasing, greater than two. For example, if the pixel clock frequency is equal to 20 MHz, a master oscillator frequency of 80 MHz would allow a pixel placement jitter accuracy of 1/4. Further, for example, with a master oscillator frequency of 240 MHz and a pixel clock frequency of about 17 MHz, the pixel jitter accuracy is 17/240.

Once the corrected pixel clock output frequency 39 is provided for each of the scanner modules 14-17, by respective pixel clock modulation circuitry 19, 70, 72, 74, the controller 18 provides for modulation of the respective laser scanners 32, 42, 46, 49 utilizing the associated corrected pixel clock output frequency 39, 76, 78, 80 for each laser scanner. For example, for laser scanner 32 the controller 18 controls laser scanner 32 using corrected pixel clock output frequency 39. Likewise, controller 18 controls laser scanner 42 using the associated corrected pixel clock output frequency 76 from pixel clock modification circuitry 70, controls laser scanner 46 using the associated corrected pixel clock output frequency 78 from pixel clock modification circuitry 72, and controls laser scanner 49 using the associated corrected pixel clock output frequency 80 from pixel clock modification circuitry 74.

Further, in reference to Figure 3, memory 31 also may include power output correction data for correcting the energy provided to photoreceptor 12 by focused beam 21. When the printing system 10 is initialized, or at any other time when the pixel placement correction data is downloaded, such power output correction data is automatically downloaded to processing unit 82. The processing unit 82 then provides the power output correction data or data associated therewith (generally shown as reference number 95) to laser diode driver 93 such that the output of the driver 93 can be modified, i.e., the amplitude of the modulation signal provided to the laser scanner is modified. The drive signal can be

modulated to achieve a constant output, or a varied output designed to compensate for nonuniform conductivity across the surface of the photoreceptor.

One skilled in the art will recognize that the use of power output correction data is advantageous when more than one laser scanner is utilized in a printing system such that by controlling the power output of the laser scanners (i.e., the power output of the laser scanner at the receptor plane) utilized in the multiple laser scanner system, tone and density of the image created by the printing system is consistent. For example, the power output of the laser scanner when using solid state lasers may be about 1 milliwatt to about 2 milliwatts. If the power output of the two or more laser scanners can be corrected such that all of the laser scanners of the multiple scanner printing system have constant power output in this power output range, then the tone and density of an image is improved.

On the other hand, as previously addressed, pixel placement correction to provide correction for variations, such as nonlinearity, due primarily to the scan lens imperfections, is applicable to a single laser scanner system, a multiple pass printing system using a single laser scanner, or a single pass multiple laser scanner printing system. In other words, use of pixel placement correction data to correct for variations, such as nonlinearities, is applicable to systems utilizing one or more laser scanners as opposed to power output correction data which is applicable mainly to printing systems using two or more laser scanners. It should be readily apparent that the present invention as described herein with respect to a single pass multiple laser system is clearly adaptable to such other systems.

As shall be described with reference to Figures 4-9, the pixel placement correction data and/or the power output correction data stored in memory of a scanner module as previously described is generated for each respective associated laser scanner separately. As such, the scanner modules include pixel placement correction data and/or power output correction data which is particularly applicable only to the laser scanner of the associated scanner module. Therefore, these scanner modules, e.g., scanner modules 14-17, are self-contained and can be easily field replaceable because they are independent of any data generated with respect to any of the other scanner modules. Further, these scanner modules

require no testing for correction of scan profile differences, such as linearity problems, at the printing system level, as the correction data is already resident with each of the scanner modules. The resident scan correction data provides a basis to correct for linearity problems associated with mechanical, optical, and electronic variations in the laser scanner, or at least conform the scanner to a target scan profile, which may be nonlinear, that is common to each of the scanners.

The manner of generating such pixel placement correction data and/or power output correction data shall be described with respect to scanner module 14 including laser scanner 32 and memory 31 housed within a single module. However, the correction data generation system 100 is equally applicable to any other scanner module.

As shown in Figure 4, the correction data generation system 100 includes a scan line detector 104 and correction data generator and scanner controller 106. The system 100 electronically characterizes the scan profile, as influenced by nonlinearities, of the laser scanner 32. The scan line detector 104 of the correction data generation system 100 is fixed at a position in the system 100. The scan line detector 104 may be any light detection apparatus capable of providing information regarding the time that a laser spot provided by laser scanner 32 is at a particular point along a scan line associated with the scan line detector. For example, as described further below in the various embodiments hereof, the scan line detector 104 may be, for example, a single light detecting element utilized in combination with a constant frequency grating or may be a plurality of discrete light detectors.

To generate the correction data, i.e., pixel placement and/or power output correction data, the scanner module 14 is positioned relative to the scan line detector 104 such that it generates a laser spot that impinges along a scan line associated with the scan line detector 104. The scan line detector 104 generates time representative signals of when a laser spot scanned along a scan line associated with detector 104 passes a plurality of points along the scan line. For example, a fixture 33 using alignment pins (not shown) holds the laser scanner module 14 relative to the scan line detector 104 such that when the laser scanner

module 14 is operable under control of correction data generator and scanner controller 106, the laser spot generated thereby is scanned along a scan line associated with the scan line detector 104. The scan line detector 104 then provides the generated time representative signals to the correction data generator and scanner controller 106. Correction data generator and scanner controller 106, in addition to controlling the laser scanner 32 for scanning the laser spot along the scan line associated with the scan line detector 104, further generates the correction data, i.e., pixel placement correction data and/or power output correction data, from the time representative signals, as shall be described further below.

A first embodiment of a portion of the correction data generation system 100 is diagrammatically shown in Figure 5. In this embodiment of the correction data generation system 100, the scan line detector 104 takes the form of a detector array 110 including a plurality of array elements 112. The array of elements 112 includes elements $n_1, n_2 \ldots n_n$ which are equally spaced along an associated scan line 12. The distance along the scan line 12 and between each detector is accurately known. The detector array 110 further includes a start of scan indicator 114 for use in synchronization of the generated pixel placement correction data. For example, the start of scan 114 corresponds with the start of scan of printing system 10 as described with reference to Figure 3.

As the laser spot 61 is scanned in the scan direction 62 along the scan line 12, time representative signals of when a laser spot 61 reaches the center of such detectors are utilized by the correction data generator and scanner controller 106 in generating the pixel placement correction data for modifying the pixel clock frequency. At each discrete detector $n_1, n_2 \ldots n_n$, the time of arrival of the laser spot 61 is noted and used in a comparison with calculated ideal times of arrival to compute pixel placement correction data. The ideal times of arrival may be representative of a linear scan profile or some other target profile to which the scanners should conform to achieve substantial image registration. Various methods of making such a comparison are possible and one such method is provided in detail below. A number of scans may be averaged to obtain an

extremely precise set of pixel placement correction data based on the time of arrival of the laser spot 61 at given discrete detectors.

One illustration of a pixel placement correction data generation method 120, is shown in the flow diagram of Figure 6. The method generally provides the calculation flow for generation of the pixel placement correction data. The scan is started and the laser spot 61 is moved in a scan direction 62 across the array of discrete elements 112. The actual time (T_{actual}) between the adjacent pair n_1 and n_2 of discrete detectors is measured. The measured T_{actual} is compared to an expected time between discrete detectors ($T_{expected}$) determined as a function of known distances and known velocities associated with a target scan profile. In the case of a linear scan profile, the expected time is determined as a function of constant velocities. If T_{actual} is less than $T_{expected}$, then laser spot 61 traveled too fast. A correction in video pixel clock frequency is therefore necessary when the laser spot resides at detector n_1 in order to actually write a dot with correct placement at detector n_2. This corrected value, f, is higher in value than the nominal frequency f_0 by the ratio $[T_{expected}/T_{actual}]f_0$, wherein f_0 is the master video clock pixel frequency provided by the master oscillator (comparable to 88, Figure 3).

Likewise, if T_{actual} is greater than the $T_{expected}$, the laser spot traveled too slow and a corresponding correction in video frequency would need to be supplied when the laser spot resides at detector n_1 in order to actually write a dot with correct placement at detector n_2. This corrected value, f, would then be lower in value than the nominal frequency (f_0), again by the ratio $[T_{expected}/T_{actual}]f_0$. This comparison would be carried out for each pair of discrete elements 112 of the array of elements 110.

Therefore, the pixel placement correction values are generated based on T_{actual} and $T_{expected}$ and the values stored in the memory would be a function of $[T_{expected}/T_{actual}]$. These pixel placement correction data values would then be read by a printer controller (such as controller 18) as previously described herein and applied to modify and generate a corrected video clock frequency for the laser scanner to which they apply in order to correctly place pixels of the latent image on photoreceptor 12 (Figure 2).

For n detectors, there are n-1 data entries in the memory 31, e.g., a look-up table, of scanner module 14. Data entry 1 will reflect any deviation from a target velocity profile, e.g., perfect linear spot velocity or some chosen nonlinear spot velocity, between detectors n_1 and n_2, as described above. Data entry 2 will reflect deviation from perfect linear spot velocity, or the chosen nonlinear target spot velocity, between detectors n_2 and n_3, etc. It should be noted that the steps above line 300 may be repeated and then averaged in order to calculate a precise set of pixel placement correction data. For example, in a 600 dpi scanner, 180 scans may be averaged in a tenth of a second to obtain an extremely precise measurement of the actual time of arrival of the spot at a given detector. After the pixel placement data correction values are generated, they arc stored in scanner memory 31.

With reference to Figure 7, the scan line detector 104 is provided by detection apparatus 130. Detection apparatus 130 includes a single detector element 132 having a constant frequency grating 134 positioned between the scan lens 64 and the single detector element 132. Detection apparatus 130 further includes a start of scan indicator 136. Pixel placement correction data generation method 140, as shown by the flow diagram of Figure 8, provides for the generation of pixel placement correction data for the detection apparatus shown in Figure 7.

The laser scanner 32 is controlled to scan the laser spot 61 in scan direction 62. If the grating lines 138 are x-lines per inch, then a pulse counter of error correction data generator 106 may be employed to issue a time T_{actual} for x/n pulses, where n may be selected to give a reading as often as required, such as 3-4 readings per inch of laser spot travel. Therefore, this arrangement will yield error data every 1/n inches along the scan line 12, e.g., every 1/4 inch. With reference to Figure 8, and similar to the description with regard to Figure 6, the T_{actual} measurements taken after a specific number of counted pulses is compared to a $T_{expected}$ value. Pixel placement correction data is then generated based on the T_{actual} and $T_{expected}$ values and stored in scanner memory 31 for use by a printer controller, such as printer controller 18, as previously described. Again, it should be noted

that the steps above line 400 may be repeated and averaged to calculate a precise set of pixel placement correction data.

The constant frequency grating 134 may be a ROCHI grating, a grating including a transmissive layer having ink printed thereon, a grating including an opaque material having openings cut therein, etc. Any constant frequency grating may be suitable for use in conjunction with the above described embodiment.

The time representative signals generated in either of the embodiments of scan line detector 104 can further be utilized to generate power output correction data as described with reference to Figure 9. The time representative signals have amplitudes which are a function of the energy impinging upon the light detecting portions of the scan line detector 104.

As shown by the flow diagram of the power output correction data generation method 150 of Figure 9, the laser spot 61 is scanned from start of scan, and the actual intensity of the focused beam impinging upon the light detecting apparatus as represented by amplitude of the signal from the scan line detector 104 is received by the correction data generator 106. The detected actual amplitude (A_{actual}) is compared to a predetermined amplitude (A_{pred}) which the user defines. A_{pred} is set at an amplitude corresponding to an intensity of the power output at which a user wants all of the laser scanners to operate for a printing system. If A_{actual} is equal to A_{pred}, then no output correction data is generated. However, if A_{actual} is not equal to A_{pred}, then a power output correction data value is generated based on the comparison. The power output correction data value is stored in the memory 31 of scanner module 14. The power output correction data value is then utilized by the processing unit in a printing system for control of the associated laser scanner for which it was generated. For example, the power output correction data value can be used as a baseline for modulation of the power output to compensate for nonuniform conductivity across the photoreceptor.

It should be apparent to one skilled in the art that various other test and generation arrangements may be utilized for generating the pixel placement correction data and/or the power output correction data. For example, a dual split detector may be utilized in addition to a high precision linear translator to

establish a plurality of detector positions as the dual split detector is moved along the scan line associated therewith by the translator. In operation, the dual split detector may be moved to a first position and a T_{actual} value generated for the first position. The dual split detector would then be moved to a second position at which another T_{actual} value would be generated, and so forth. Pixel correction data would be generated in a manner similarly described with reference to Figure 6.

By providing pixel placement correction data for each scanner, multiple scanners in an electrophotographic imaging system can be, in effect, calibrated to a target scan profile. Specifically, differences in the scan profiles of multiple scanners can be reduced by adjusting the pixel clock frequency for each scanner based on the pixel placement correction data associated with the scanner such that the scanners converge toward a substantially common target scan profile. The substantially common target scan profile can be linear or nonlinear so long as it is shared by each of the scanners. In this manner, the latent images formed by the scanners can be placed in substantial registration with one another. The registration may occur on the photoreceptor surface in the event the latent images are formed and developed on top of one another, or on a transfer surface in the event the latent images are formed at different positions along the photoreceptor surface and placed in registration upon development and transfer to an output surface. In either case, nonlinearities or other scanner-to-scanner variations can be compensated by adjusting pixel placement, thereby alleviating the visual effects of the variations in the final multi-color image.

Similarly, by providing power output correction data for each scanner, multiple scanners in an electrophotographic imaging systems can be calibrated to a desired laser output intensity given common laser drive data. In this manner, differences in laser response to drive data can be reduced among the multiple laser scanners. Further, the laser output can be modulated to compensate for photoreceptor nonuniformities. Consequently, the visual effects of varying output power and/or photoreceptor nonuniformity can be alleviated, contributing to enhanced image quality.

What we claim is:

1. A field replaceable scanner module for use in an imaging system, the scanner module comprising:

a laser scanner operable under control of the imaging system for scanning a laser spot along a scan line to write a plurality of pixels along the scan line; and

scanner module memory including pixel placement correction data downloadable to the imaging system for use in controlling the placement of pixels along the scan line.

2. The scanner module according to claim 1, wherein the scanner module memory further includes output power correction data downloadable to the imaging system for use in controlling the output power of the laser scanner in the generation of the plurality of pixels along the scan line.

3. The scanner module according to claim 2, wherein the scanner module includes an input/output port for input of the pixel placement correction data and output power correction data to the scanner module memory, and further for output of the pixel placement correction data and output power correction data to the imaging system.

4. The scanner module according to claim 1, wherein the laser scanner includes a scan lens for focusing a laser beam from a laser source, the scan lens causing the laser scanner to scan the laser spot along the scan line at a nonconstant velocity resulting in pixel placement error, and further wherein the pixel placement correction data for use in controlling the placement of pixels to correct for the pixel placement error is generated by a test system separate from the imaging system and the pixel placement correction data is loaded in the scanner module memory through an input/output port of the scanner module.

5. The scanner module according to claim 4, wherein the pixel placement correction data is used by the imaging system in varying a pixel clock of a video signal used for placement of pixels to correct the pixel placement error.

6. An imaging system comprising at least one scanner module as defined by any of claims 1-5, and further comprising a controller having a scanner profile memory, the controlling controlling the laser scanner to scan the laser spot along the scan line to write the plurality of pixels along the scan line, wherein the pixel placement correction data stored in the scanner module memory is downloadable to the scan line profile memory of the controller for use in controlling the placement of pixels along the scan line.

7. The system according to claim 6, wherein the controller controls the placement of pixels for each scanner module by using the pixel placement correction data to vary a pixel clock frequency for the scanner module to correct for pixel placement error.

8. The system according to claim 6, wherein the controller controls a single pass color imaging system using three or more of the scanner modules to generate a color image, each of the three or more scanner modules being separably replaceable scanner modules.

9. The system according to claim 8, wherein the controller controls the placement of pixels for each of the three or more scanner modules by using the pixel placement correction data downloaded to the scan line profile memory of the controller from the three or more scanner modules to modify a separate pixel clock frequency for each of the three or more scanner modules.

10. The system according to claim 9, wherein the pixel placement correction data is automatically downloaded to the scan line profile memory of the controller when the imaging system is initialized.

11. A method of pixel placement correction, the method comprising the steps of:

providing a laser scanner having a scan lens that causes the laser scanner to scan a laser spot along a scan line at a particular velocity resulting in pixel placement error along the scan line relative to a desired pixel placement;

generating pixel placement correction data by scanning the laser spot along a scan line, detecting actual time periods of when the laser spot passes by separated points along the scan line, comparing the actual time periods to expected time periods, and generating the pixel placement correction data based on the comparison;

storing the pixel placement correction data associated with the laser scanner in memory of a scanner module containing the laser scanner prior to the laser scanner being utilized with an imaging system;

positioning the scanner module in an imaging system for operation and control thereby; and

downloading the pixel placement correction data to memory of the imaging system for use by the imaging system in controlling placement of pixels to correct for the pixel placement error.

12. A system for performing the method of claim 11, the system comprising:

a light detection apparatus for generating time representative signals of when the laser spot scanned along the scan line associated with the light detection apparatus passes the separated points s along the scan line;

a fixture for holding the laser scanner module relative to the light detection apparatus, such that when the laser scanner module is operable, the laser spot is scanned along the scan line associated with the light detection apparatus; and

a processing device for generating the pixel placement correction data for use by the imaging system in controlling the placement of pixels along the scan line, wherein the pixel placement correction data is generated based on the time representative signals.

13. The system according to claim 12, wherein the light detection apparatus includes an array of n discrete light detectors positioned along the scan line, the light detectors generating the time representative signals as the laser spot passes each of the discrete light detectors.

14. The system according to claim 12, wherein the processing device detects (n–1) actual time values between signals generated by pairs of adjacent discrete detectors as the light spot passes thereby and compares the actual time values to expected time values to provide a time error for use in the generation of the pixel placement correction data.

15. The system according to claim 11, wherein the light detection apparatus includes:

a single light collecting element positioned along the scan line generating signals as the light impinges thereon; and

a constant frequency grating including a plurality of separated transmissive regions, the grating positioned between the single light collecting element and the laser scanner.

16. A laser scanning system comprising:

a first laser scanner that scans a first laser beam with a first scan profile;

a second laser scanner that scans a second laser beam with a second scan profile; and

a scan controller that controls the first and second laser scanners to reduce differences between the first and second scan profiles.

17. The system of claim 16, wherein the scan controller controls the first and second laser scanners to adjust both the first scan profile and the second scan profile toward a target scan profile.

18. The system of claim 16, further comprising:

a first memory containing first scan correction data; and

a second memory containing second scan correction data,

wherein the controller accesses the first memory to retrieve the first scan correction data and controls the first scanner based on the first correction data to adjust the first scan profile toward a target scan profile, and

wherein the controller accesses the second memory to retrieve the second scan correction data and controls the second scanner based on the second scan correction data to adjust the second scan profile toward the target scan profile.

19. The system of claim 18, wherein the first scanner includes a first scanner module, the first memory being contained within the first scanner module, and the second scanner includes a second scanner module, the second memory being contained within the second scanner module.

20. The system of claim 18, wherein the first scanner scans first pixels along a first scan line, the second scanner scans second pixels along a second scan line, and the difference between the first and second scan profiles includes a difference in placement of the first and second pixels along the first and second scan lines.

21. The system of claim 20, wherein the controller controls the placement of the first pixels by the first scanner based on a first pixel clock frequency and controls the placement of the second pixels by the second scanner based on a second pixel clock frequency, the controller varying the first pixel clock frequency based on the first scan correction data as the first scanner scans the first pixels and varying the second pixel clock frequency based on the second scan correction data as the second scanner scans the second pixels, the controller applying the first and second adjusted pixel clock frequencies to reduce the difference in placement of the first and second pixels by the first and second scanners.

22. The system of claim 21, wherein the controller includes a first controller having a first direct digital synthesizer that generates the first pixel clock frequency based on the first scan correction data, and a second controller having a second direct digital synthesizer that generates the second pixel clock frequency based on the second scan correction data.

23. The system of claim 16, wherein the controller controls the first scanner to scan a plurality of first pixels representative of a first color separation image, and the controller controls the second scanner to scan a plurality of second pixels representative of a second color separation image, and wherein the controller controls the first and second scanners such that the first and second color separation images are in substantial registration with one another on the scanned surface.

24. The system of claim 23, further comprising:

a third laser scanner that scans a third laser beam with a third scan profile; and

a fourth laser scanner that scans a fourth laser beam with a fourth scan profile,

wherein the controller controls the third scanner to scan a plurality of third pixels representative of a third color separation image, and the controller controls the fourth scanner to scan a plurality of fourth pixels representative of a fourth color separation image, and

wherein the controller controls the first, second, third, and fourth laser scanners to reduce differences between the first, second, third, and fourth scan profiles such that the first, second, third, and fourth color separation images are in substantial registration with one another on the scanned surface.

25. A method for controlling a plurality of laser scanners in a laser scanning system, the method comprising:

driving a first laser scanner to scan a first laser beam, wherein the first laser scanner has a first scan profile;

driving a second laser scanner to scan a second laser beam, wherein the second laser scanner has a second scan profile; and

controlling the first and second laser scanners to reduce differences between the first and second scan profiles.

26. The method of claim 25, further comprising controlling the first and second laser scanners to adjust both the first scan profile and the second scan profile toward a target scan profile.

27. The method of claim 25, further comprising:

storing first scan correction data in a first memory;

storing second scan correction data in a second memory;

accessing the first memory to retrieve the first scan correction data;

accessing the second memory to retrieve the second scan correction data;

controlling the first scanner based on the first correction data to adjust the first scan profile toward a target scan profile, and

controlling the second scanner based on the second scan correction data to adjust the second scan profile toward the target scan profile.

28. The method of claim 27, wherein the first scanner includes a first scanner module, the first memory being contained within the first scanner module, and the second scanner includes a second scanner module, the second memory being contained within the second scanner module.

29. The method of claim 27, wherein the first scanner scans first pixels along a first scan line, the second scanner scans second pixels along a second scan line, and the difference between the first and second scan profiles includes a difference in placement of the first and second pixels along the first and second scan lines.

30. The method of claim 29, further comprising:

controlling the placement of the first pixels by the first scanner based on a first pixel clock frequency;

controlling the placement of the second pixels by the second scanner based on a second pixel clock frequency;

varying the first pixel clock frequency based on the first scan correction data as the first scanner scans the first pixels; and

varying the second pixel clock frequency based on the second scan correction data as the second scanner scans the second pixels,

thereby reducing the difference in placement of the first and second pixels by the first and second scanners.

31. The method of claim 30, further comprising using a first direct digital synthesizer to adjust the first pixel clock frequency, and using a second direct digital synthesizer to adjust the second pixel clock frequency.

32. The method of claim 25, further comprising controlling the first scanner to scan a plurality of first pixels representative of a first color separation image, and controlling the second scanner to scan a plurality of second pixels representative of a second color separation image, and controlling the first and second scanners such that the first and second color separation images are in substantial registration with one another on the scanned surface.

33. The method of claim 32, further comprising:

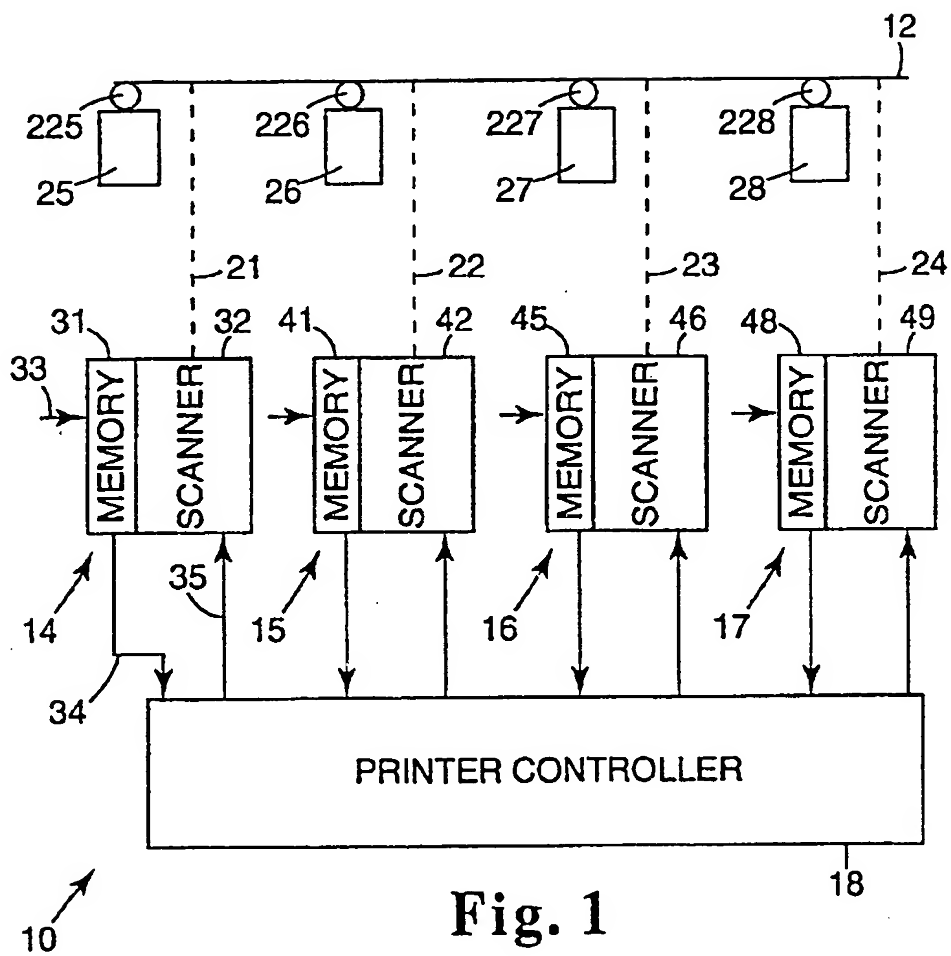
driving a third laser scanner to scan a third laser beam with a third scan profile, wherein the third laser scanner has a third scan profile;

driving a fourth laser scanner to scan a fourth laser beam with a fourth scan profile, wherein the fourth laser scanner has a fourth scan profile;

controlling the third scanner to scan a plurality of third pixels representative of a third color separation image;

controlling the fourth scanner to scan a plurality of fourth pixels representative of a fourth color separation image; and

controlling the first, second, third, and fourth laser scanners to reduce differences between the first, second, third, and fourth scan profiles such that the first, second, third, and fourth color separation images are in substantial registration with one another.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225
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MEMORY
SCANNER
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MEMORY
SCANNER
14
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17
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PRINTER CONTROLLER
18
10

Fig. 1

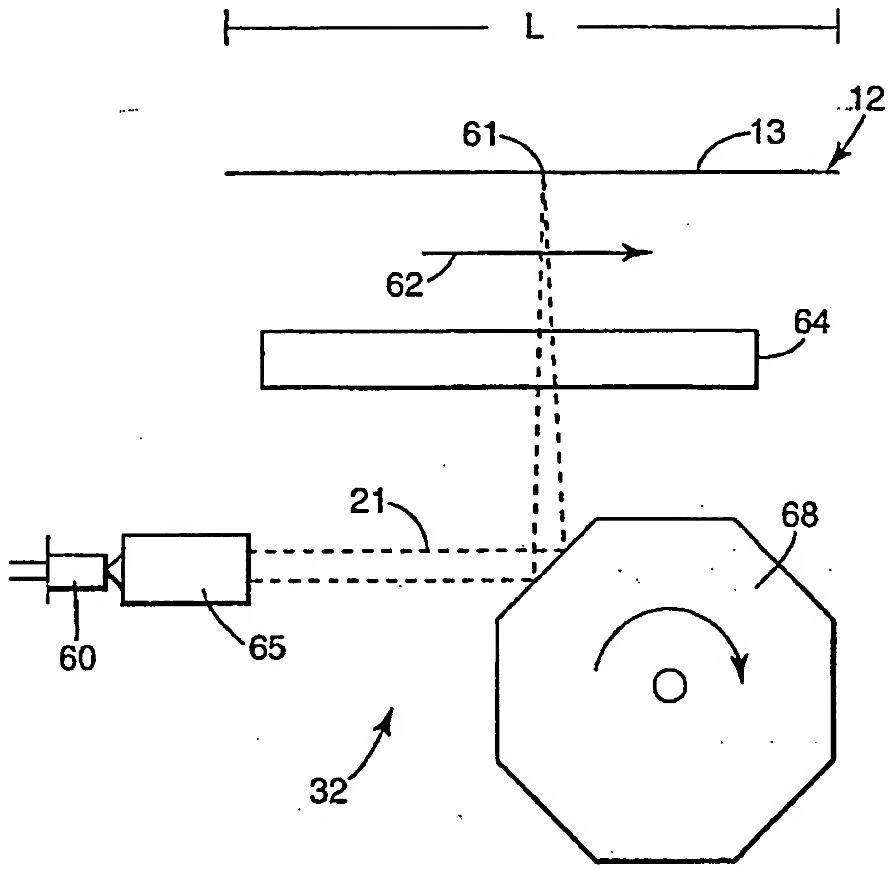

Fig. 2

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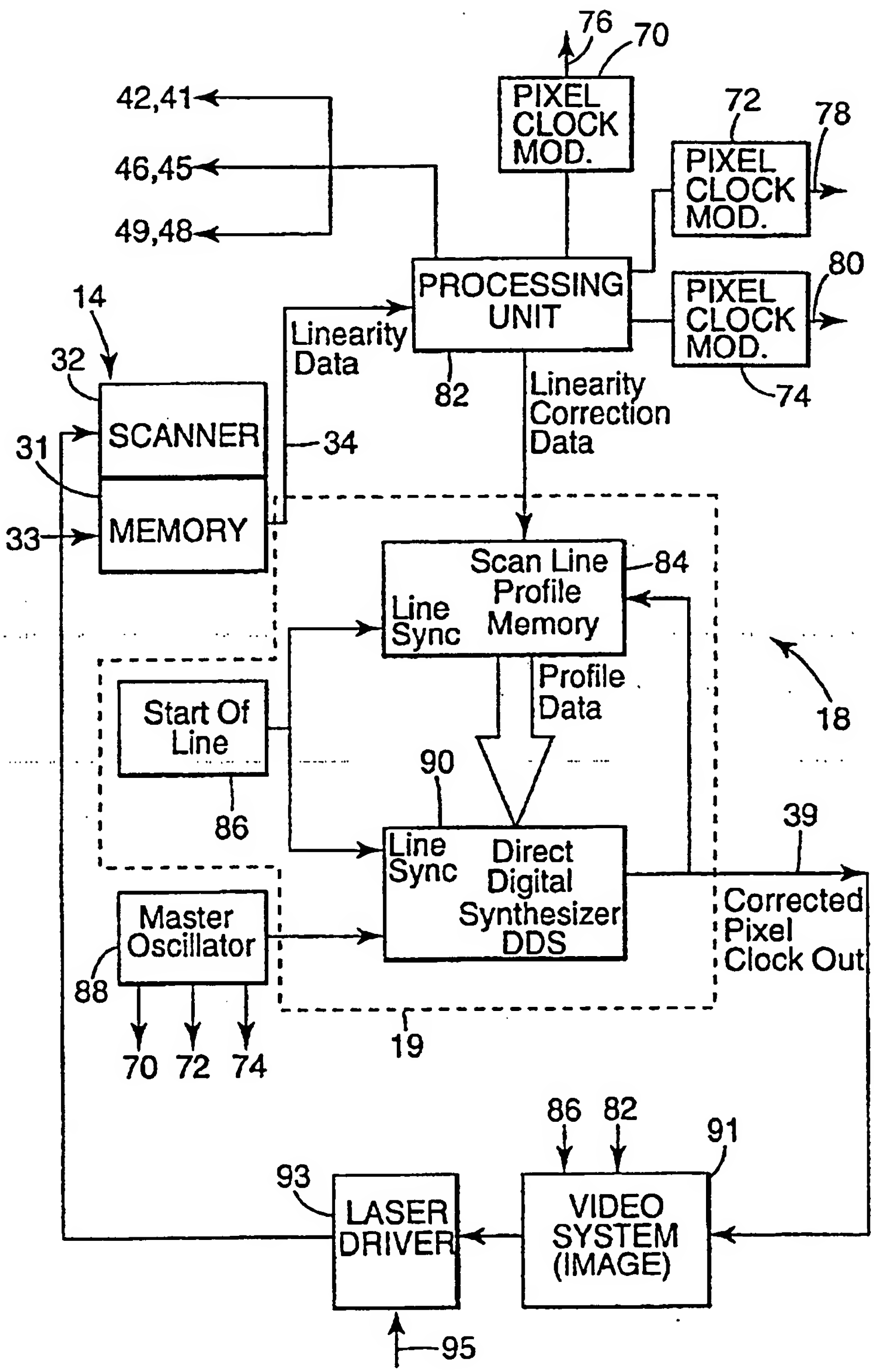
76
70
PIXEL CLOCK MOD.
42,41
46,45
49,48
72
78
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PROCESSING UNIT
80
PIXEL CLOCK MOD.
14
32
Linearity Data
82
74
Linearity Correction Data
SCANNER
31
34
MEMORY
33
Scan Line Profile Memory
Line Sync
84
Profile Data
18
Start Of Line
90
86
39
Line Sync
Direct Digital Synthesizer DDS
Corrected Pixel Clock Out
Master Oscillator
88
70 72 74
19
86 82
91
93
LASER DRIVER
VIDEO SYSTEM (IMAGE)
95

Fig. 3

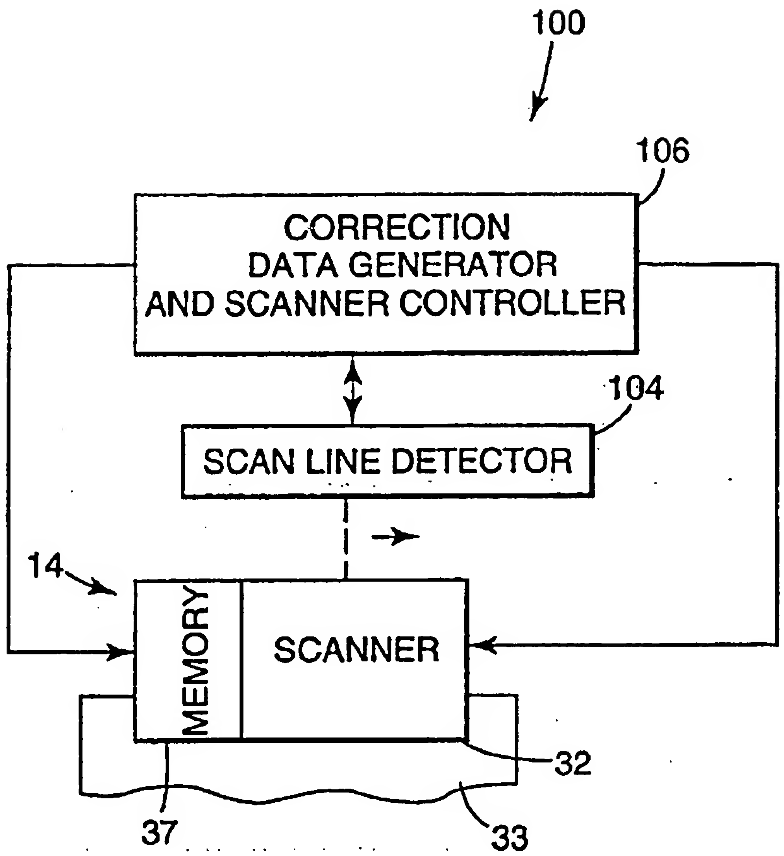
100
106
CORRECTION
DATA GENERATOR
AND SCANNER CONTROLLER
104
SCAN LINE DETECTOR
14
MEMORY
SCANNER
32
37
33

Fig. 4

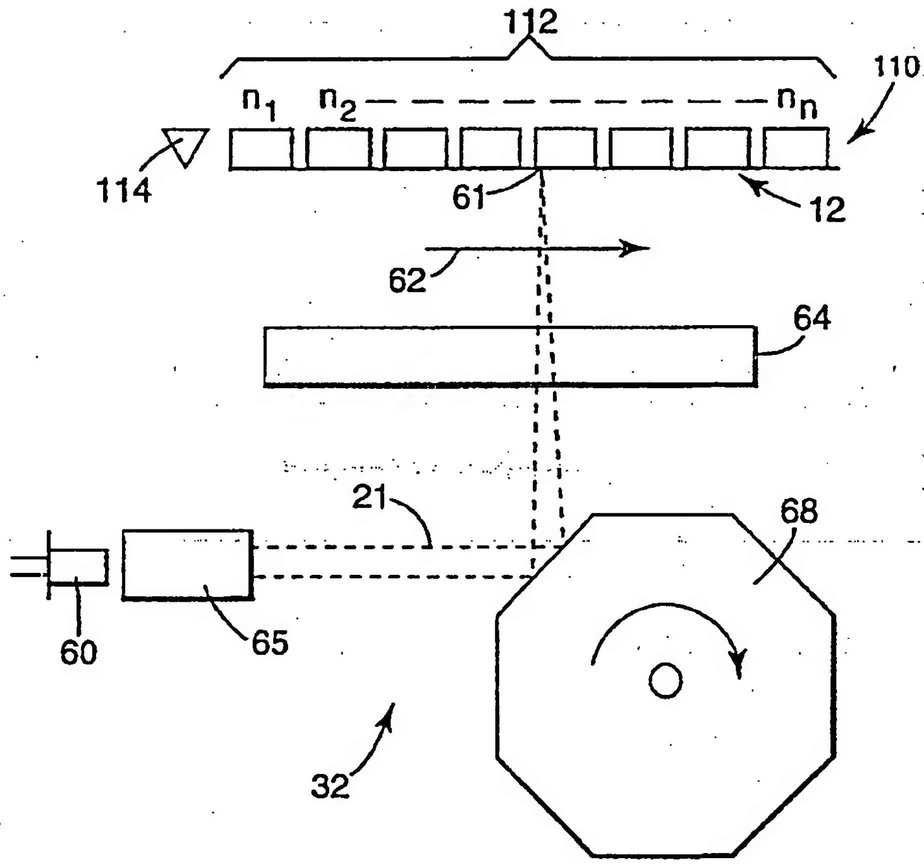

Fig. 5

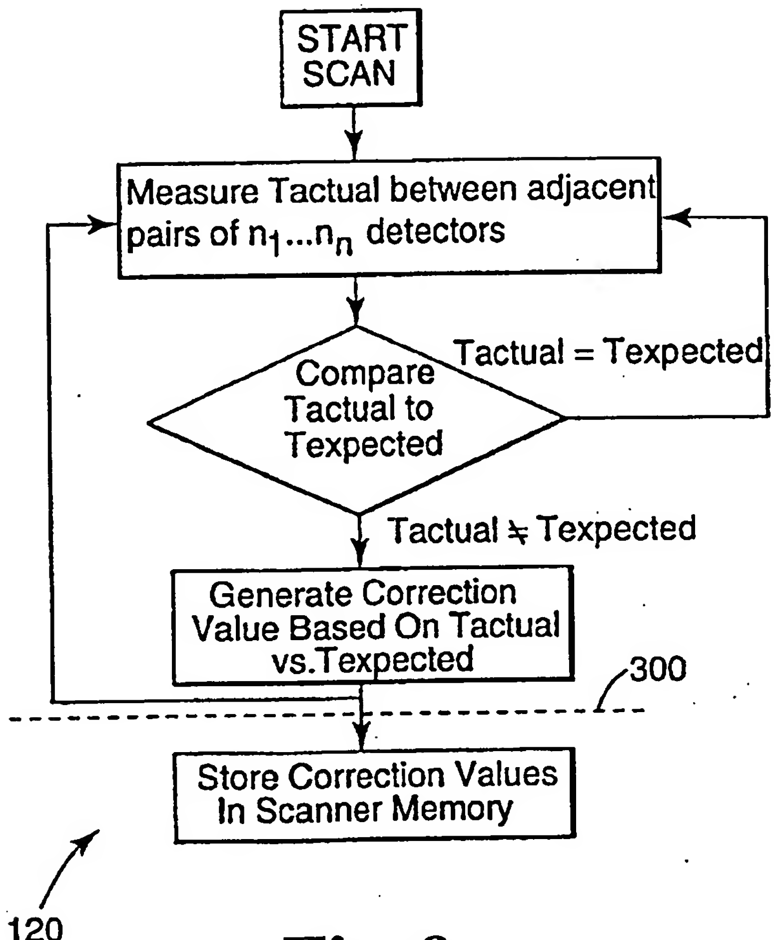
START SCAN
Measure Tactual between adjacent pairs of n1...nn detectors
Compare Tactual to Texpected
Tactual = Texpected
Tactual ≠ Texpected
Generate Correction Value Based On Tactual vs.Texpected
300
Store Correction Values In Scanner Memory
120

Fig. 6

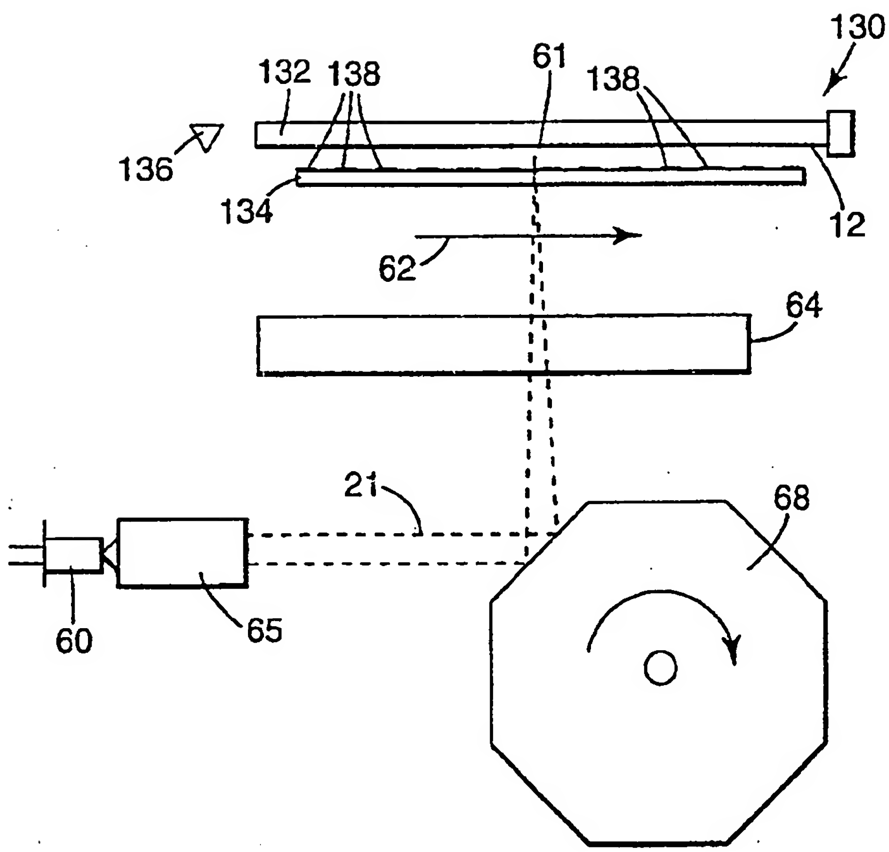

Fig. 7

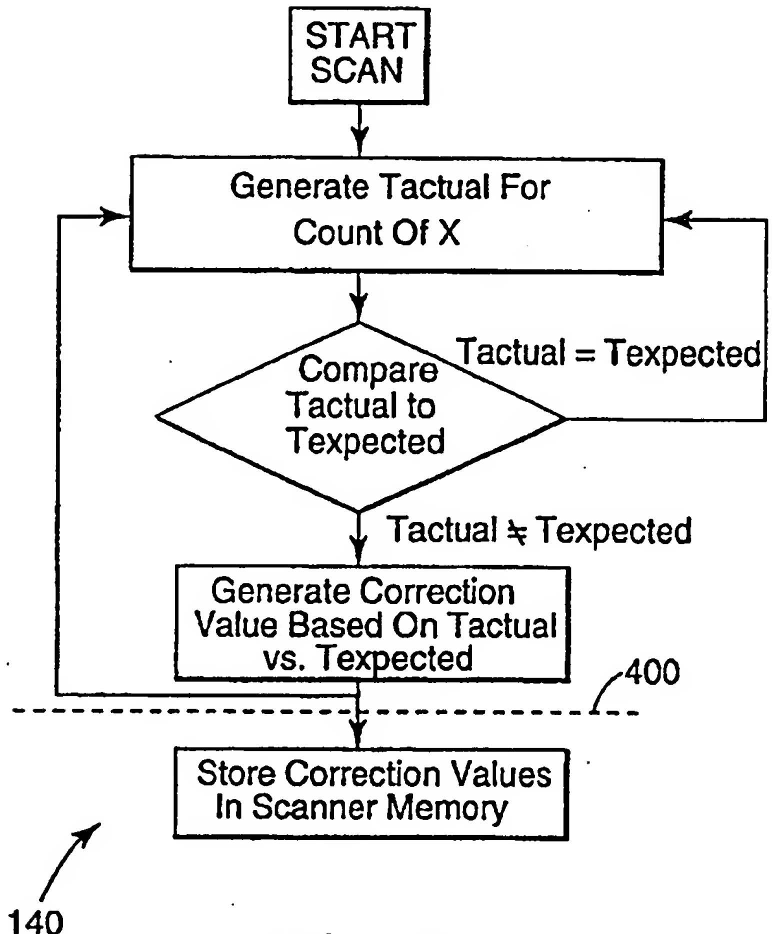
START SCAN
Generate Tactual For Count Of X
Compare Tactual to Texpected
Tactual = Texpected
Tactual ≠ Texpected
Generate Correction Value Based On Tactual vs. Texpected
400
Store Correction Values In Scanner Memory
140

Fig. 8

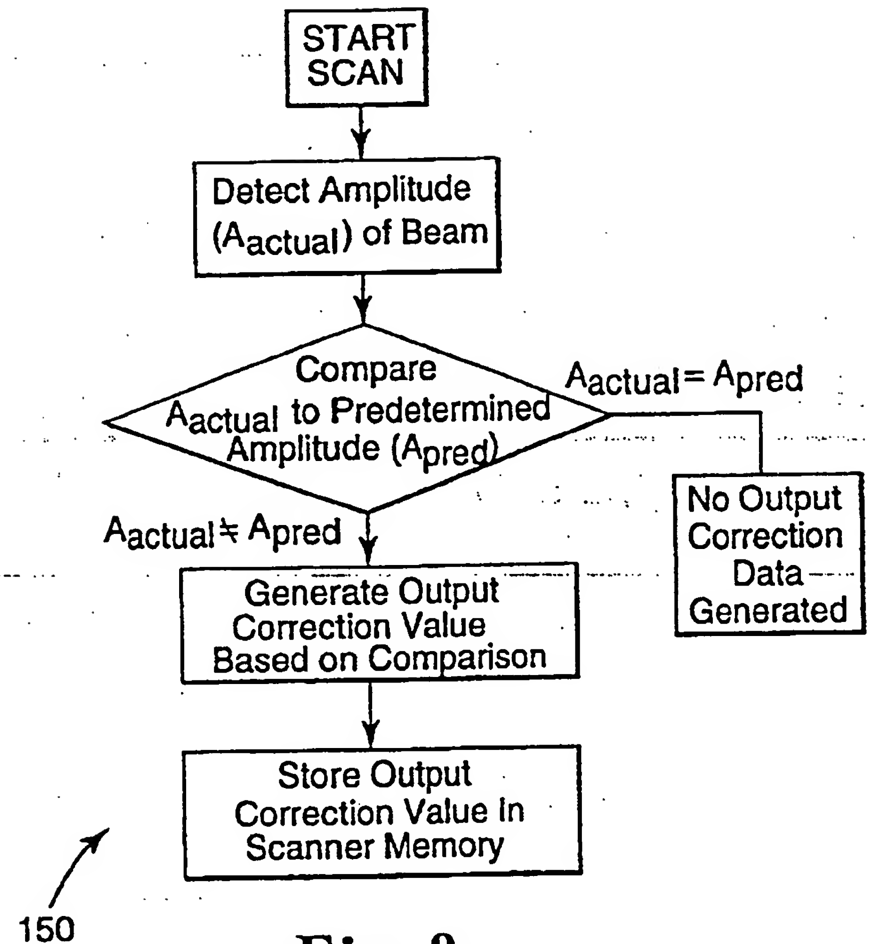
START SCAN
Detect Amplitude (A_{actual}) of Beam
Compare A_{actual} to Predetermined Amplitude (A_{pred})
$A_{actual} = A_{pred}$
No Output Correction Data Generated
$A_{actual} \neq A_{pred}$
Generate Output Correction Value Based on Comparison
Store Output Correction Value In Scanner Memory
150

Fig. 9

INTERNATIONAL SEARCH REPORT

Intel. onal Application No
PCT/US 98/11212

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04N1/053 H04N1/50 H04N1/60

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 845 358 A (ASADA KENICHIROU) 4 July 1989	16,17, 23-26, 32,33
A	see the whole document	8
Y	CURRY D N: "POLYGON LASER SCANNER FAST SCAN SPATIAL LINEARITY CORRECTION" PROCEEDINGS OF THE INTERNATIONAL CONGRESS ON ADVANCES IN NON IMPACT PRINTING TECHNOLOGIES, ORLANDO, OCT. 21 - 26, 1990, no. CONGRESS 6, 21 October 1990, pages 979-985, XP000222273 NASH R J	1,4-7
A	see the whole document	3,11,12, 15, 20-22, 29-31

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 September 1998	23/09/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hazel, J

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Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y A	EP 0 732 839 A (SHARP KK) 18 September 1996 see abstract	1,4-7 11
A	EP 0 366 037 A (DAINIPPON SCREEN MFG) 2 May 1990 see page 5, line 22 - page 6, line 35	13,14

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